If the decrease of wind velocity is due to forest growth it is natural to expect the rate of decrease to be greater in summer, when the trees are in leaf, than in winter, when they are bare. In order to test this, secular trend lines were obtained by fitting a straight line to the data for each month and for the year by least square methods. The results are given in table 3.

The average trend in percentage is 0.68 for the 6-months May–October, when the trees are in leaf, 0.55 for November–April when bare. The coefficient of correlation of the annual wind velocity with the years is −0.84. The monthly data are much more variable and give smaller coefficients of correlation.

RECORD NOVEMBER FOG PRECEDING PHENOMENAL WINTER OF 1933–34 IN THE PACIFIC NORTHWEST

By Archer B. Carpenter

[Weather Bureau, Portland, Oregon, June 1934]

The outstanding winter of 1933–34 was preceded, in November, by the greatest amount of dense fog ever recorded in the Pacific Northwest. Dense fog occurred at every airway and first-order station in the states of Oregon and Washington. The number of days with dense fog ranged from 3 at La Grande, Oreg., to 25 at Wolf Creek, Oreg.; the number of hours with dense fog during the month ranged from 5 at La Grande, to 217 at Eugene, Oreg. (See table 1.)

In a search for the cause of this unusual amount of fog, many interesting facts were discovered. The first is the relation between pressure distribution and the formation of fog. Using the Portland 4-hourly airway maps as a

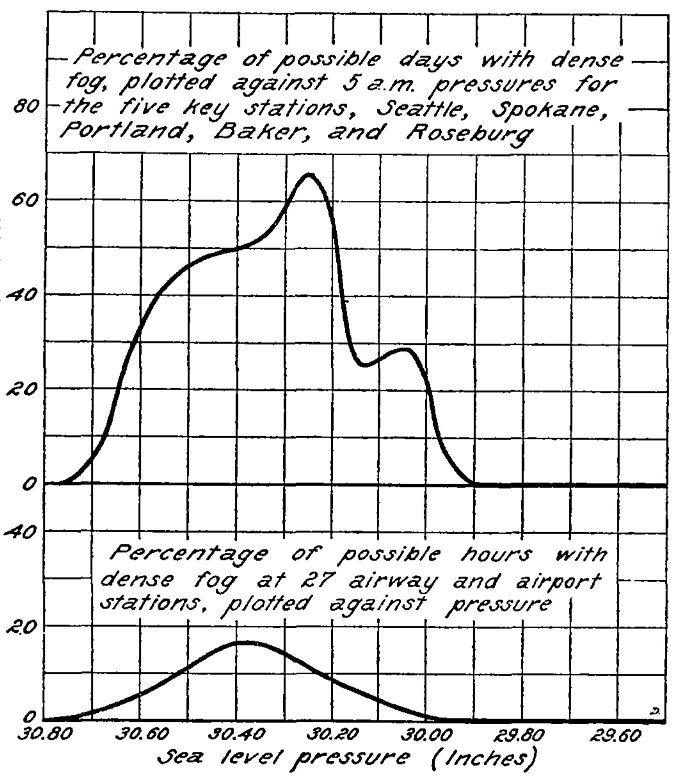

Figure 1.—Fog and pressure graphs for Pacific-Northwest, November 1933.

basis, all reports of dense fog in Oregon, Washington, southwestern Idaho, and northern California were tabulated according to the barometric pressure at the time when fog occurred. (See table 2.) This analysis was carried further by tabulating all hourly pressure reports, with or without dense fog, at the 27 airway and first-order stations. The percentage of possible hours with dense fog was then determined; the results are shown on graph A, figure 1.

The relation between pressure and days with dense fog was developed for the five key stations, Seattle, Spokane, Portland, Baker, and Roseburg. The 5 a. m. pressure reports were arbitrarily chosen because they were closely associated with fog conditions. The pressures were tabulated according to station and day of month; then those for days on which dense fog occurred were segregated, and the percent of possible days with fog was determined for each pressure. The results are shown on graph B, figure 1.

It will be noted that 88.2 percent of the dense fog occurred at pressures of 30.2 inches or above. This leads directly to a major contributing cause—the pressure over the Northwest was 0.15 to 0.27 inch above normal for the month of November, and thus was well within the limits favorable to formation of fog.

A review of storm tracks during the month will, in part, explain the unusually high pressure. On the 2nd of November a storm moved west to east through central Washington. From that time until November 27, no storms moved in through the Pacific Northwest. However, 9 storms did move in just north of Prince George, through a belt some 600 to 900 miles north-northeast of Portland, Oreg.; this distance seems to be ideal for fog formation in Washington and Oregon.

November 1933 eclipsed all previous years of record with a collective total of 58 days with dense fog at the stations of Seattle, Spokane, Portland, Baker, and Roseburg. These stations were selected because their length of record facilitates comparison with other years having excessive fog. Second in rank is November 1905, with a collective total of 43 days with dense fog; storm tracks were all north of Prince George, British Columbia, except one on the last day of the month. Then follows the year 1917, with a November collective total of 41 days with dense fog; all storms moved in north of Prince George. Next in rank are the years of 1923, 1922, and 1907; for these years similar conditions prevailed, except that a storm track through the Northwest in the opening days of November becomes more prevalent. In a study of other years with large collective totals, it becomes evident that the collective total of days with dense fog for the Northwest *decreases* in proportion to the number of storms moving inland *south* of Prince George.

A storm moving in through the Northwest very early in November, or late in October, is favorable to production of fog. The immediate reason is evident, as radiation fog is common in a stagnant, saturated air-mass from the Pacific Ocean. When such an air-mass is allowed to stagnate, fog sets in quickly and soon becomes widespread. Stagnation, however, depends on a new series (1) of LOWS starting immediately through the channel mentioned, just north of Prince George. This new series effectively shuts off the usual outburst of dry continental air following the eastward movement of a storm. Such an outburst of dry, cold air through the Northwest would quickly wash the stagnant, saturated air-mass out to sea. Insolation following such an outburst of continental air is usually sufficient to eliminate any possibility of widespread fog. However, with the new series of storms following one after another, through the channel north of Prince George, no continental air is allowed to reach the Pacific Northwest. The latter condition was fulfilled almost perfectly during November 1933.

Nearly all intermissions between days with dense fog came when storms passing inland reached unusually large size, thus bringing the Pacific Northwest under the influence of the storm, and causing an overcast condition instead of fog, with a small amount of accompanying precipitation.

The interplay of November rain and fog at Portland is interesting, and can briefly be stated as follows: Light to moderate rain on 1st to 3d, inclusive (total 1.83); dense fog reported on 6th to 11th, inclusive; light rain on 11th and 12th (trace); light rain on 15th and 16th (total 0.03); dense fog reported on 16th to 20th, inclusive; light rain on 19th (total 0.31); light rain on 21st (total 0.01); dense fog reported on 22d and 23d; light rain on 23d and 24th (total 0.05); dense fog reported on 25th and 26th; light rain on 26th and 27th (total 0.31); dense fog reported on 29th. This was definitely the end of the foggy weather, which was followed by a period of rain during December, with an excess of 10.73 inches at Portland over a normal of 6.72 inches. The deficiency in November precipitation for Portland was 3.56 inches below a normal of 6.10 inches.

The above November deficiency for Portland is strongly in contrast with an excess of 4 inches at Juneau, 8 inches at Ketchikan, 13 inches at Prince Rupert, 26 inches at Swanson Bay, and 22 inches at Ocean Falls. Precipitation at each of the last three stations along the Canadian west coast was more than double the normal November rainfall. The precipitation at Estevan, British Columbia, was nearly normal; and southward along the Washington and Oregon coast it was increasingly below normal. The above data are introduced to show the effect of a continuous series of storms moving consecutively over one track.

A closer study of the relation between fog in the Pacific Northwest and heavy rainfall along the coast of Canada and southern Alaska reveals facts of considerable interest. The first long period with dense fog followed a storm moving in through the Northwest on November 2. Fog conditions thus produced were maintained by another storm in the Gulf of Alaska which gave Ketchikan 1.98 inches precipitation on the 5th, 6th, and 7th. Following a 1-day lull, another storm gave Ketchikan a 3-day total of 4.60 inches. Then followed another 1-day lull, in the wake of a large storm which later produced the duststorm of November 12 and 13, 1933. This storm covered a wide strip from South Dakota eastward to the St. Lawrence Valley. Portland, Oreg., had a full day of sunshine on November 13 and almost a full day on the 14th. On the above 2 days Ketchikan received 4.8 inches precipitation. It was the southeast return of air from this storm that again produced ideal fog conditions in the Northwest by November 16. Five days with dense fog at Portland followed. This fog condition was maintained similarly to the first one, that is, by another storm immediately following, which gave Ketchikan 6.52 inches of rain on November 17 and 18. Rainfall at Ketchikan also reached a maximum during each of the remaining shorter fog periods. A short review of previous years likewise reveals a close association between heavy rainfall at Ketchikan and prolonged fog in the Pacific Northwest (fig. 2).

This series of storms, passing inland just to the north of Prince George, British Columbia, produced interesting effects in the air masses over the Northwest. The air-mass designations are those used by Willett (2), and a careful attempt has been made to classify the air masses according to his specifications. Use was made of forenoon temperatures aloft, as reported by commercial aircraft every few minutes while in flight; upper-air wind directions and velocities from pilot-balloon ascensions; air-mass trajectory from Map A Pacific; and surface temperatures, dew points, and wind records from 4-hourly airways maps prepared at Portland, Oreg. Upper-air humidity records for November were not available, thus injecting considerable uncertainty into classification.

The air mass on November 6 was classed as Neutralized Polar Pacific (Npp) air in the low levels, and Neutralized Tropical Pacific (Ntp) air aloft. The Npp air was a stagnation of the fresh Polar Pacific (Pp) air that remained in the Pacific Northwest after the storm of November 2 had passed inland. The Ntp air aloft had

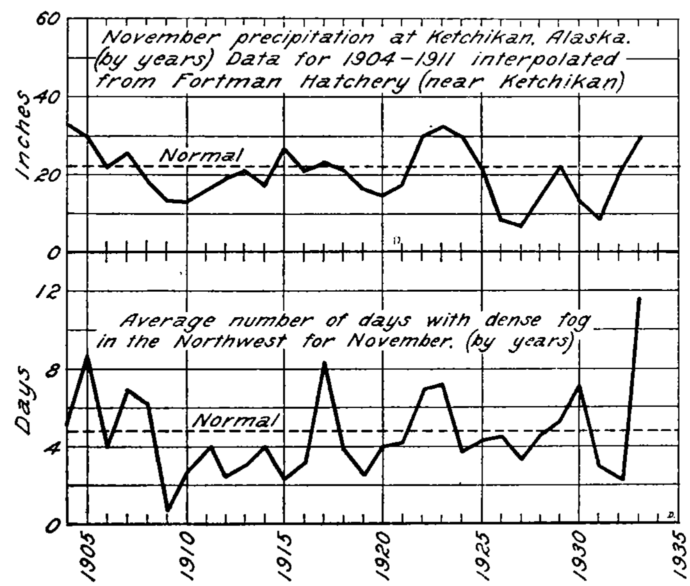

FIGURE 2.

its source in a large portion of the Pacific HIGH, which had been pushed into southwestern Canada by a storm developing in the usual location of the Pacific HIGH. Portland winds aloft on November 6 were northerly up to 10,000 feet, with a tendency to north-northwest in the higher levels. The entire mass up to 7,000 feet was almost isothermal, except for a low inversion layer. Actual temperatures ranged from 48° F. to 52° F. at altitudes between 2,000 and 7,000 feet. No reports were available above 7,000 feet. The low inversion extended to approximately 2,000 feet at 10 a. m. with surface temperature 41° and dew point 40°. By afternoon, when the fog and low stratus clouds cleared away, nine-tenths of the sky was covered with alto-cumulus clouds moving from the northwest.

In the days following November 6, the top of the inversion increased steadily in height and temperature, reaching a maximum height of 6,000 feet November 12 with a temperature of 70°. The surface dew point at Portland increased slowly from 40° to 44° on the above

6 days. Available upper-air wind reports indicated a predominance of southwesterly winds of moderate velocity above 4,000 feet and southeasterly winds of moderate velocity below that altitude. These southeasterly winds were mostly of Columbia Gorge origin. The temperatures at Crown Point, elevation 743 feet, at the western end of the Columbia Gorge, averaged 1° lower than Portland airport temperatures during foggy weather. Adiabatic heating of this air as it reached lower elevations in the Portland area was sufficient to maintain the flow at an elevation above the surface fog stratum. The following relation holds true in nearly all cases. With easterly velocities under 25 miles per hour at Crown Point, and temperatures not more than one degree colder than at the Portland Airport, no turbulence whatever was noted in the fog stratum at the airport. With greater velocities and similar temperatures, the turbulence was felt in proportion to the increased velocity, with resultant slow dissipation of fog. With temperatures at Crown Point equal or slightly higher than at the Portland airport, easterly velocities in excess of 40 miles per hour at Crown Point were needed to produce turbulence in the surface fog stratum at the airport.

The source of this prevailing warm easterly gorge wind was usually a drainage down the Columbia River Basin from the Canadian Rockies in southwestern Canada. Air in this region was nearly always Ntp, having lost most of its moisture along the Canadian coast in the excessive rains at Ketchikan and Prince Rupert, but maintaining its warmth. To reverse the order of thought an almost continuous pressure gradient existed during November from south to north over the Pacific Ocean. This gradient favored a steady flow of tropical (Tp) air northeastward to the Canadian coast, where precipitation for the month was twice the normal. From there, the air-mass, now classified as Ntp, was carried southeastward in the southwest quadrants of a series of storms moving inland. That portion of Ntp air which was carried into the upper reaches of the Columbia River was partially cooled in the low levels by radiation, and flowed down the course of the Columbia River to reach the Pacific Northwest. The inherent warmth of the mass, and the moderate velocities attending the flow, due to this residual heat, made it impossible for the air flowing down the Columbia Gorge or over mountain passes to affect the fog strata in the coastal valley from Seattle to Roseburg. The heating produced by the warm air passing over these fog strata was balanced by radiational cooling during the lengthening November nights. This radiational cooling also had to overcome the afternoon insolation when fog and low clouds cleared away.

The only days during this November with 100 percent sunshine at Portland, came on November 5 and 13. The 5th was previous to the beginning of fog at Portland, and the 13th followed a temporary lapse in the storm series north of Prince George, allowing additional cooling in the air flow down the Columbia River drainage. On November 12, at 10 a. m. the air at Crown Point was 6° colder than at Portland, quite in contrast to the 6 days just preceding, when 10 a. m. temperatures at Crown Point were very nearly equal to those at Portland. The temperature of the air for these 6 days, reduced to Portland elevation, would have been higher, but the Crown Point temperature on November 12, even when reduced to Portland elevation would still be lower. The result was a washing out of the foggy stratum in the Portland area. However, the flow was not strong enough to materially affect the foggy strata in the Willamette Valley and Roseburg areas.

Air-mass conditions for the second long period of fog from November 16 to 20, were very similar to those for the first period. The original cold surface fog stratum was formed in Npp air; upper air temperatures and winds were almost identical, and a similar relation prevailed between temperatures at Crown Point and Portland. While the Portland area has been used as an example, the relations apply to the whole coastal valley to a lesser extent, applying least in the Roseburg area.

A relation also exists between fog in the Northwest and a preceding cold winter in central Alaska. The record at Fairbanks began in 1904, and was chosen as being the best available; 73 percent of the years with November fog above normal in the Northwest were preceded by subnormal winter temperatures at Fairbanks. Most interesting are the 3 years, 1907, 1917, and 1933. The mean temperature for the 3 months of the winter of 1906–7 was −12° F. (The normal mean temperature for the 3 winter months at Fairbanks is −5.5°.) In November 1907 the Northwest had an average of 7 days with dense fog. This average is based on records for the stations at Seattle, Spokane, Portland, Baker, and Roseburg. (The normal average for these stations is 4½.) For the winter of 1916–17, the mean temperature was −8.3° at Fairbanks, and the following November produced an average of 8 days with dense fog in the Northwest.

The winter of 1932–33 at Fairbanks (**3**) was severe, with a mean temperature for the 3 winter months of −14.5°. November 1933 followed with an average of 12 days with dense fog at the above-mentioned stations in the Northwest. The average for November 1933 was taken from regular Weather Bureau office records, so that it would be comparable to other records before the advent of airport stations. Substituting airport records for city office records, where possible, the average is increased to 14.

It is interesting to note that floods occurred in the Willamette River in December 1907, 1917, and 1933, and that heavy floods occurred in western Washington (**5**) in the last 2 years mentioned above. The Novembers of 1917 and 1933 were both preceded, and followed, by record-cold temperatures in central Alaska. On January 27, 1933, the temperature dropped to 60° F. below zero, and this temperature was also reached in 1916, just previous to the November and December phenomena in 1917. The years 1917 and 1933 both ended in unusually mild winters in the Northwest, and severe winters throughout Alaska and the Northeastern States (**4**).

There is a strong possibility that records covering a longer period may show a correlation between severe winters in central Alaska, November fog and December floods in the Northwest, and severe cold in the Northeastern States.

TABLE 1.—*Days and hours with fog in Northwest for November 1933*

Station	Light fog		Moderate fog		Dense fog	
	Days	Hours	Days	Hours	Days	Hours
Portland-Medford Airway:						
Portland, Oreg	23	106	18	103	16	88
Salem, Oreg	25	104	22	76	19	133
Eugene, Oreg	25	111	20	65	22	217
Roseburg, Oreg	26	95	17	54	23	169
Wolf Creek, Oreg	0	0	6	6	25	165
Sexton Summit, Oreg. (elevation 3,855 feet)	2	3	1	2	7	81
Medford, Oreg	16	51	11	17	15	109
Portland-Seattle Airway:						
Castle Rock, Wash	26	283	22	62	19	111
Chehalis, Wash	28	178	21	83	15	88
Tacoma, Wash	24	125	19	103	18	187
Seattle, Wash	28	223	21	101	15	71
Portland-Pasco-Spokane Airway:						
Portland, Oreg	23	106	18	103	16	88
Crown Point, Oreg. (elevation 743 feet)	14	36	6	8	13	82
Cascade Locks, Oreg	14	40	3	6	7	29
Hood River, Oreg	17	41	6	11	3	13
North Dalles, Wash	12	57	3	5	5	16
Umatilla, Oreg	8	39	7	16	5	22
Pasco, Wash	8	38	3	8	3	15
Spokane, Wash	16	74	10	22	9	61
Pasco-Boise Airway:						
Pasco, Wash	8	38	3	8	3	15
La Grande, Oreg.[1]	5	9	2	6	3	5
Baker, Oreg.[1]	5	15	4	10	4	15
Weiser, Idaho.[1]	5	6	13	26	15	59
Boise, Idaho	9	23	0	0	0	0

[1] Data for intermediate stations on this airway interpolated from sequence reports.

TABLE 2.—*Reports of dense fog at 4-hourly periods with pressure at which fog occurred and percentage of cases*

Total cases reported November 1933	Sea-level pressure	Percentage of cases	Total cases reported November 1933	Sea-level pressure	Percentage of cases
	Inches			*Inches*	
6	30. 00–30. 09	1. 2	104	30. 40–30. 49	20. 8
53	30. 10–30. 19	10. 6	19	30. 50–30. 59	3. 8
125	30. 20–30. 29	25. 1	2	30. 60–30. 69	0. 4
189	30. 30–30. 39	37. 9	1	30. 70–30. 79	. 2

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WINTER FOGS IN THE GREAT VALLEY OF CALIFORNIA

By R. C. COUNTS, Jr.

[Weather Bureau, San Francisco, Calif., August 1934]

An effort is made in the following discussion to establish two facts concerning fogs in the Great Valley of California: First, that the more extensive fogs have their inception only after the first seasonal rains, and that their development at any time during the winter is dependent on a wet ground. Second, that in the initial stages of their development they appear as ground fogs, or as fogs with the lower surface resting on or within a few feet of the ground,[1] rather than in the form of stratus cloud.

This Great Valley, which comprises the Sacramento and San Joaquin valleys, is an elongated area covering 20,000 square miles, roughly, and is surrounded by mountains averaging approximately 3,000 feet in height on the westward side, and more than 5,000 at the northern and southern extremities and on the eastward side. By the configuration of the land, the valley is protected from any horizontal movement of the air, except through a few passes in the coastal range, a condition which permits atmospheric stagnation, and favors its prolongation. It is during these quiescent states that protracted spells of fog and stratus cloud occur in the winter months; fogs of such extent and persistence as to impede or prevent travel by auto, train, or airplane, and therefore of much concern to operators of public conveyances. Some concept of the extent of these fogs may be acquired from the fact that during January of 1934, there were 350 hours with fog or stratus cloud, at no time with a ceiling higher than 1,000 feet, at Fresno, and 335 hours at Sacramento, or very nearly one-half of the entire 744 hours of the month. Fogs with their inferior surface resting on the ground occurred in varying degrees of intensity on 28 days of this month at Fresno and on 23 days at Sacramento. In this connection it is well to state that the data in this paper were obtained from the charts at the San Francisco office of the Weather Bureau and from the forms of the various airport stations in the valley. These forms contain for each day an hourly record of the temperature, dew point, wind direction and velocity, horizontal visibility, and height of ceiling.

The beginnings of these long periods of stagnation in the cooler months of the year usually are associated with subsidence in the Polar Pacific[2] air-mass which overspreads the far west after the passage of a cyclone to the eastward. Fogs develop readily in the valley under these conditions, and are frequent from the latter part of November to February. If rains are general and of appreciable amounts in the valley immediately preceding these stagnant conditions, fog often engulfs the entire area for a period of from several days to the major part of a month. Through the winter months the days are only about 10 hours in length and the sun's altitude relatively low, so that warming in the daytime is not adequate to offset the loss of heat by radiation during the much longer nights from the ground and the moist stratum of air usually confined in the valley under stagnation. Fogs do not occur in this season alone; they also form in the early spring and late fall, but with considerably less frequency, and usually are of short duration. This, of course, would be expected since the nights are much shorter, and nocturnal cooling by radiation is too often insufficient to lower the temperature to the dew point through the required depth of moist air.

The first occurrence of fog in the season occasionally is in the fall months after there has been a definite trend to cooler weather and the nights have become materially longer. But, it is almost axiomatic with the district forecasters at the Weather Bureau office in San Francisco that fogs or stratus clouds of a general character do not develop until after the first seasonal rains; and that if their development does not follow within a few days of the first rainy spell it will be delayed until after a later rain. The close relation between rains and fogs in the

[1] Dense fogs of considerable thickness; the term "ground fog" applies to fog which obscures objects on the ground, but does not materially obscure the sky. Both types are to be distinguished from stratus cloud or "high fog".

[2] Referred to in this paper as such, although it usually is modified or transitional Polar Pacific air.